Validation of tropospheric parameters estimating from VLBI data analysis

(ID# G53B-0727)

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Introduction

Atmospheric water vapor is one of the largest contributors to the error budget for modeling signal time propagation in radio technique observations. In order to validate the tropospheric parameters estimated from VLBI data analysis, we compared the estimates with co-located WVR measurements and GPS estimates of total zenith delay.

We analyzed the VLBI observations carried out during the continuous VLBI campaign CONT05 using the two independent analysis software packages CALC/SOLVE and SteelBreeze. We estimated tropospheric zenith delays for each VLBI station applying different approaches. The estimates were compared with corresponding solutions obtained from the analysis of GPS observations and results of water vapor radiometer measurements.

Available Data

A suitable data set for validation of wet zenith delay (WZD) estimations is a VLBI campaign of two-weeks of continuous observations, CONT05, conducted in September 2005. For this period there are publicly available WVR measurements for four VLBI stations. Also, estimations of total zenith delays (TZD) from GPS data analysis are publicly available from the IGS site (the solution is provided by JPL AC).

VLBI solutions: We used two independent VLBI data analysis softwares, CALC/SOLVE and SteelBreeze. Data analysis was performed applying the same models and procedures as for regular VLBI analysis routines. Main differences between the two solution: CALC/SOLVE models wet zenith delay as a linear piecewise function (with a step of one hour between nodes) and estimates values at the nodes from observations using least square method, while SteelBreeze software treats the delays as stochastic parameters (random walk model) and estimates them using a Square Root Information Filter.

WVR measurements: Four of the eleven sites that participated in the CONT05 campaign have provided results of WVR measurements: Algonquin Radio Observatory, NRC, Canada (ALGOPARK), Kokee Park Geophysical Observatory, USNO/NASA, USA (KOKEE), Tsukuba 32-m VLBI station, GSI, Japan (TSUKUB32) and Fundamentalstation Wettzell, BKG, Germany (WETTZELL). Radiometers at two of these sites, KOKEE and WETTZELL, have observed water distribution at different angles of elevation and azimuth by performing a tip-curve calibration. The radiometers at ALGOPARK and TSUKUB32 were pointed at zenith.

GPS estimations: In our comparison we used a final solution of tropospheric parameters that was produced by the GPS data analysis center at JPL and made available on the IGS site. Due to lack of pressure data at every GPS site, the data analysis center reports total zenith delays.

Comparison of Wet Zenith Delays

Before comparison of WZD we performed a cleaning of WVR results. Outliers and data contaminated by rain have been removed. Then, for KOKEE and WETTZELL data the equivalent zenith path delays have been evaluated using the Niell Mapping Function. For each epoch of VLBI estimation we calculated the corresponding average zenith delay from WVR zenith delays. After that, two WZD time series, VLBI- and WVR-derived, were compared. Parameters of the linear transformation

$$\mathrm{VLBI} = A + B \cdot \mathrm{WVR}$$

have been estimated and the WRMS of residuals have been evaluated.

The results obtained are summarized in the table below. The shifts (A) and residuals (WRMS) are in mm. Also, the numbers of common points (N) are shown.

	SteelBreeze				CALC / SOLVE			
Station	A	B	WRMS	N	A	B	WRMS	N
ALGOPARK	-4.3	0.901	10.1	1826	-9.6	0.927	6.48	304
KOKEE	1.6	0.963	5.76	4046	1.7	0.970	5.78	304
TSUKUB32	-14.1	0.930	5.73	3053	-13.8	0.933	5.84	174
WETTZELL	-0.8	0.910	4.78	3800	-1.1	0.918	4.18	340

As one can see from the table, the scatter of WZD differences obtained with independent techniques are on the level of 5mm. The shifts and slopes are caused by different reasons: (1) In the VLBI data analysis some part of water vapor is already accounted for as part of the hydrostatic zenith delay; however, it is measured by WVR. (2) Applied calibrations for radiometers may not correspond to the local conditions. (3) Different heights of a VLBI antenna and a WVR instrument.

Comparison of Total Zenith Delays

To compare total zenith delays, we evaluated hydrostatic zenith delays using ambient pressure and site coordinates and added these values to the WZD measurements of the WVR. We then repeated the procedures described above to compare the WVR-, VLBI- and GPS-derived total zenith delays. In the table below the results of comparing GPS estimated TZD and the TZD derived from WVR measurements and VLBI data analysis are shown.

	GPS = A + B·WVR				GPS = A + B·VLBI			
Station	A	B	WRMS	N	A	B	WRMS	N
ALGOPARK	498	0.794	10.8	3270	10	1.000	11.5	864
KOKEE	121	0.942	5.07	2843	88	0.963	5.54	3362
TSUKUB32	338	0.865	11.1	2022	34	0.989	5.57	3743
WETTZELL	248	0.888	4.39	3703	60	0.976	3.96	3354

The shifts and slopes here have the same origin as in the case of the WZD. Comparison of VLBI and GPS estimates of TZD displays their good agreement: the scale factor (B) is close to unity and WRMS residuals are about 5 to 10 mm.

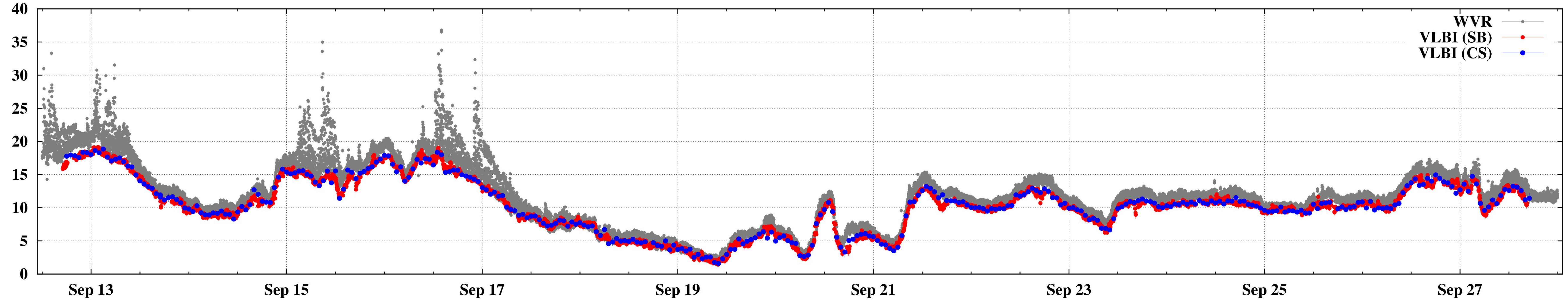


Figure 1. Wet zenith delays (cm) at Wettzell. Results of water vapor radiometer (WVR) measurements and VLBI estimates with SteelBreeze (SB) and CALC/SOLVE (CS) software.

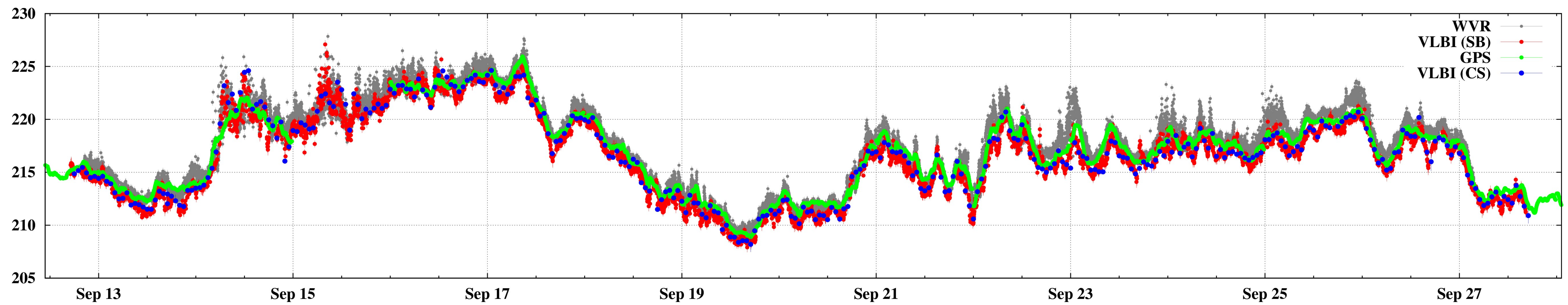
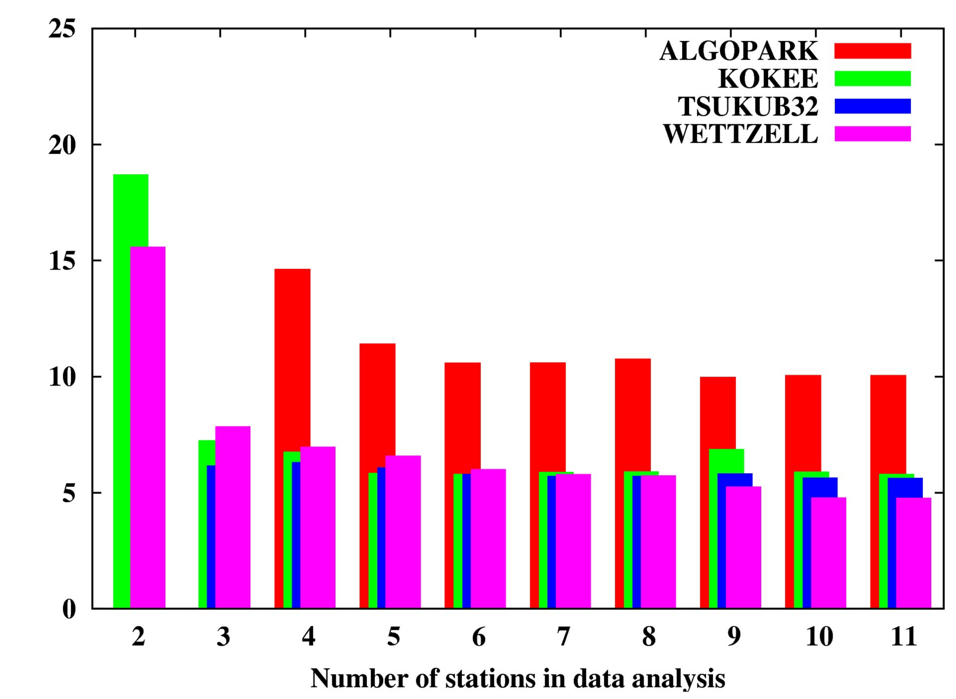


Figure 2. Total zenith delays (cm) at Kokee. Results of water vapor radiometer (WVR) measurements, GPS and VLBI estimates with SteelBreeze (SB) and CALC/SOLVE (CS) software.

Network configuration test



To check the reliability of estimated wet zenith delays from VLBI data analysis and its dependence on network configuration we performed a simple test: from the full CONT05 network of stations we excluded one VLBI station, made standard data analysis and evaluated the WRMS residuals of wet zenith delays with respect to WVR data. We then excluded a second station and repeated the procedure. The chart on the left displays the WRMS residuals (in mm) as a function of the number of stations in data analysis. The whole CONT05 network consists of eleven VLBI stations.

Order of excluded stations: TIGOCONC(10), HARTRAO(9), WESTFORD(8), ONSALA60(7), SVETLOE(6), NYALES20(5), GILCREEK(4), ALGOPARK(3) and TSUKUB32(2).

Conclusions

- Comparison of WZD estimates obtained with independent VLBI data analysis software shows good agreement.
- Agreements for wet zenith delays between water vapor radiometer data and estimates from radio technique observations, VLBI and GPS, are good. The WRMS residuals of mutual differences are on the level of 5-10 mm.
- Network configuration test shows that (excluding an extreme case of one baseline) WZD estimations from VLBI data analysis are close enough to WVR measurements and the residuals change only slightly with number of stations and processed observables.

2010 AGU Fall Meeting. Abstract ID# G53B-0727

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